Remote Sensing of Cloud Top Heights using the Research Scanning Polarimeter

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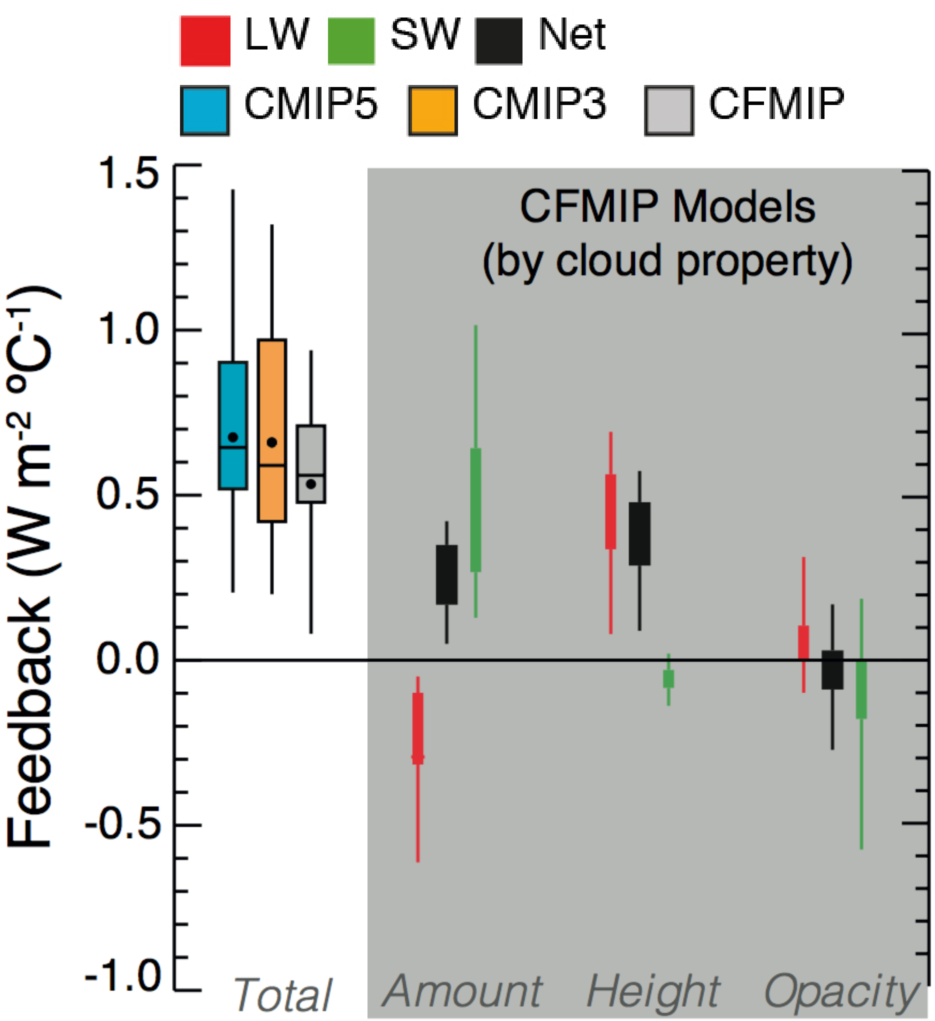
Motivation

- Cloud top height (CTH) is critical for the Research Scanning Polarimeter (RSP) when studying:
  - cloud thermodynamic phase
  - particle size distributions
  - asymmetry parameter
- Interested in exploring the RSP's ability to sense multiple cloud layers
- Models indicate that cloud height increases in a warming climate result in a positive cloud-height feedback
- Global-scale observations of CTH changes have yielded uncertain results



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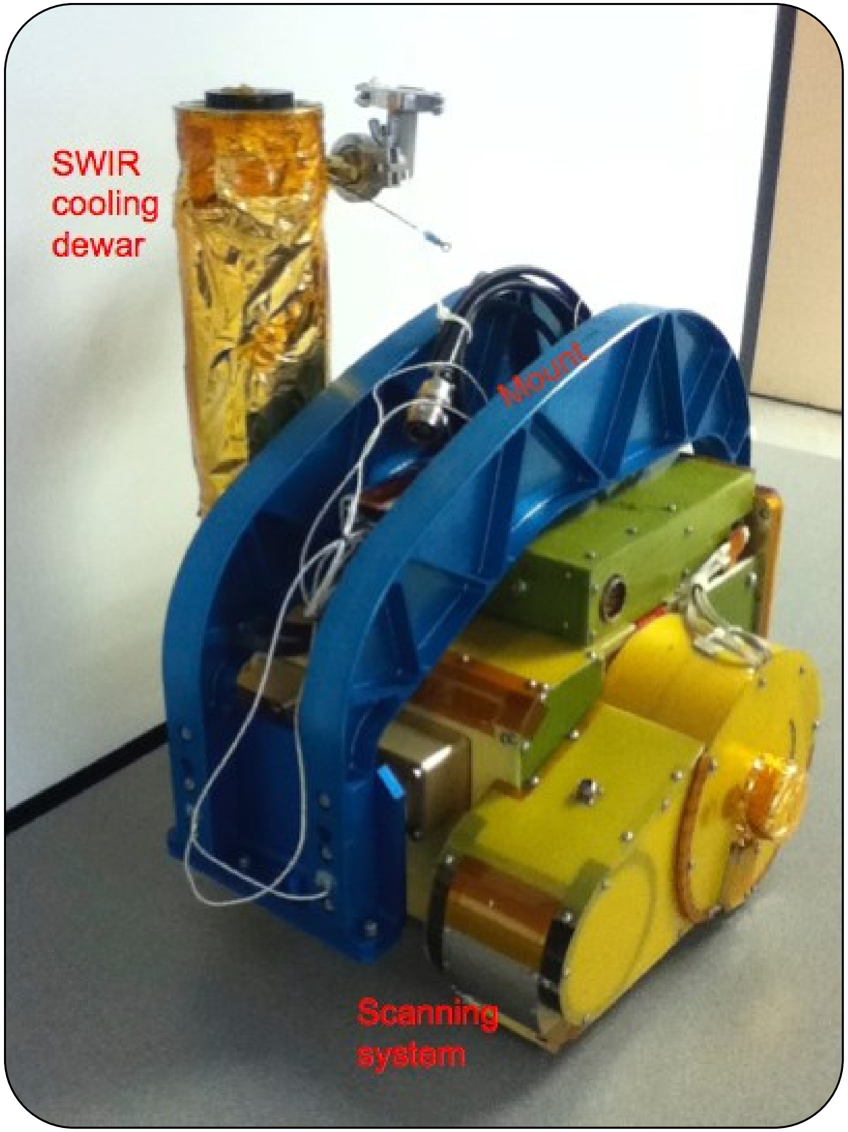
Introduction

Research Scanning Polarimeter

- Prototype for Aerosol Polarimetry Sensor on the Glory satellite (2011)
- Along track scanning - 152 viewing angles per scene (±60°)
- 14 mrad field of view (~280 m on ground from 20 km alt.)
- Polarimetric and full intensity measurements in the visible and shortwave infrared over 9 bands:
  - 410, 470, 555, 670, 864, 960, 1593, 1880, 2263 nm for aerosols and clouds
  - 1880 nm for high-altitude measurements



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Measurements

- RSP: using 2 channels: 1880 nm & 670 nm
- Cloud Physics Lidar (CPL)
  - 30 m vertical resolution
  - Accurate up to an optical depth of ~3.0
  - Data products used: cloud top height, cloud bottom height, extinction, layer classification (aerosol, cloud, PBL)
- Data used in this analysis was collected over 9 days during the NASA SEAC^{4}RS experiment
  - August 6th, 21st and September 2nd, 4th, 11th, 13th, 16th, 18th and 22nd 2013

Photo credits (top): Carla Thomas

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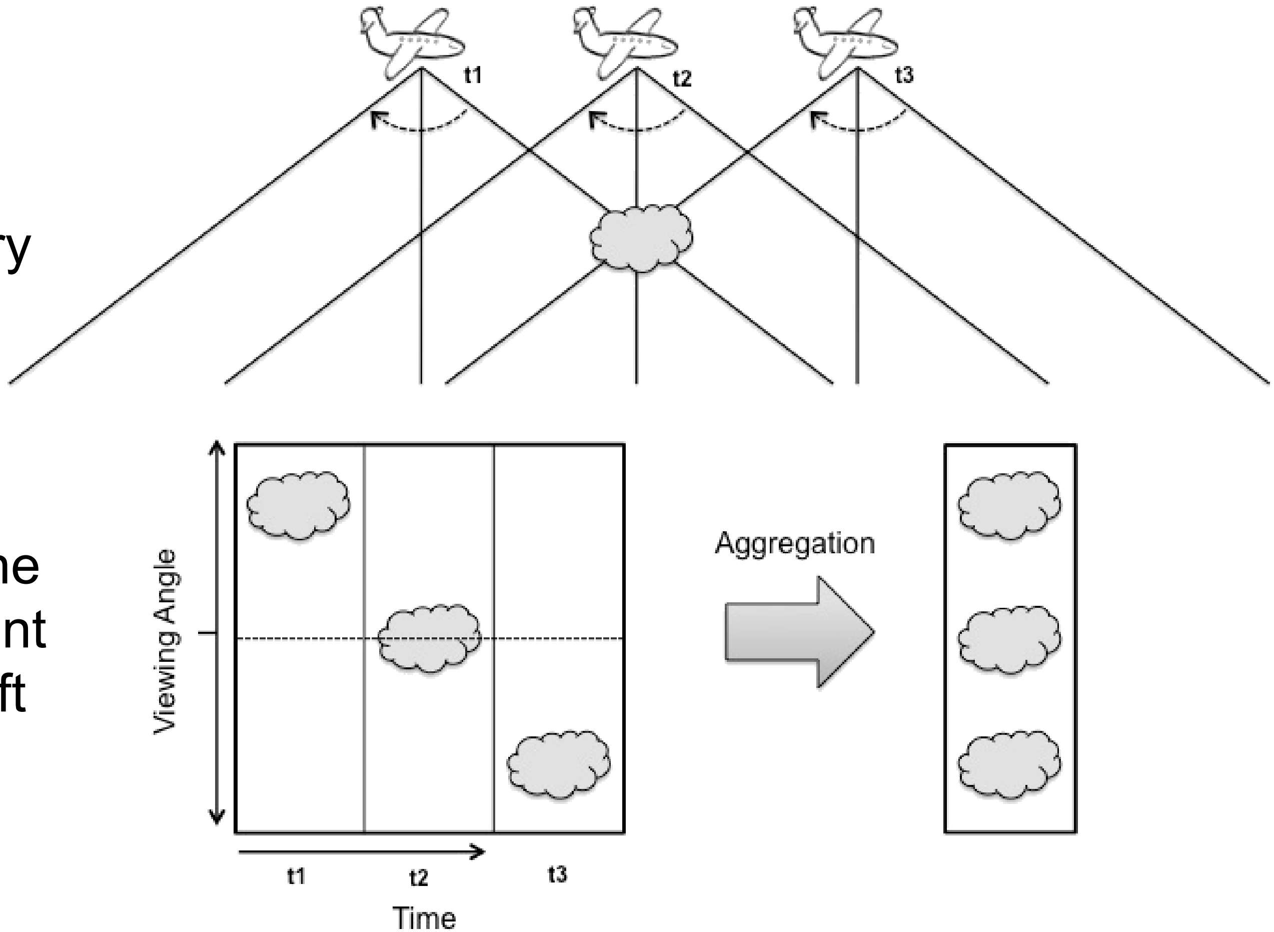
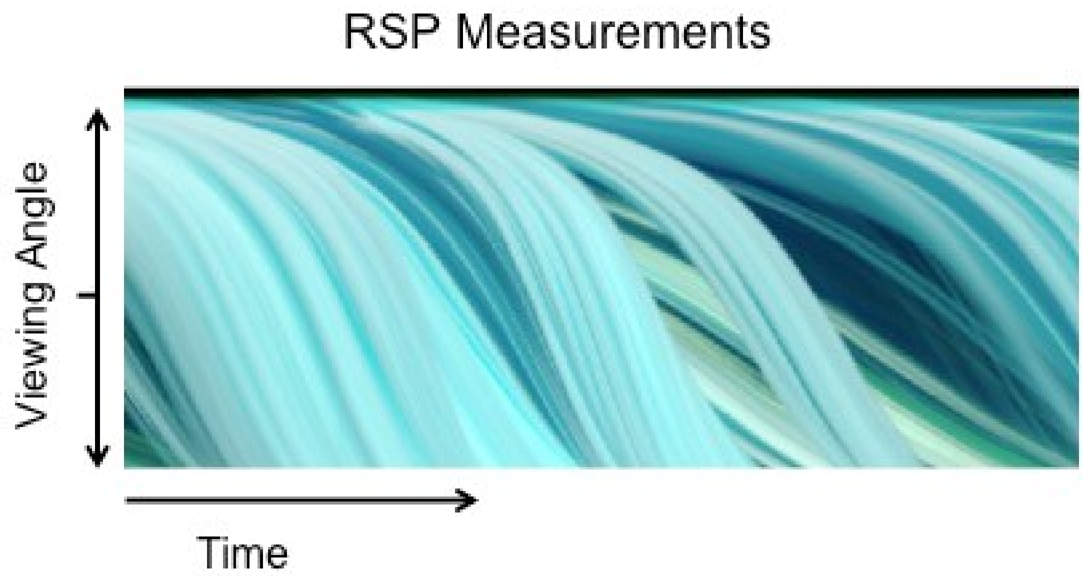
RSP CTH Retrieval Method

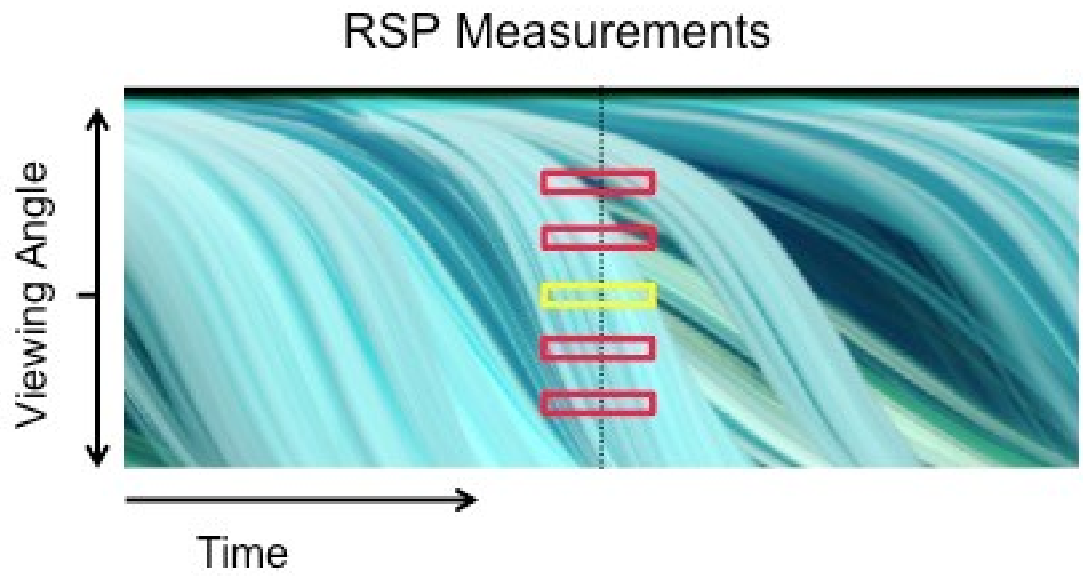
- Uses the concept of *parallax*.
- Distance from a stationary object is related to the displacement when observed from different viewing angles
- Accurate knowledge of the geometry of the instrument and position of the aircraft is essential for stereo reconstruction




RSP Measurements
Viewing Angle
Time

Multilayer Sensing

- Take a set of consecutive measurements
- Calculate the correlation between this set and equa sized sets at other viewing angles



Multilayer Sensing

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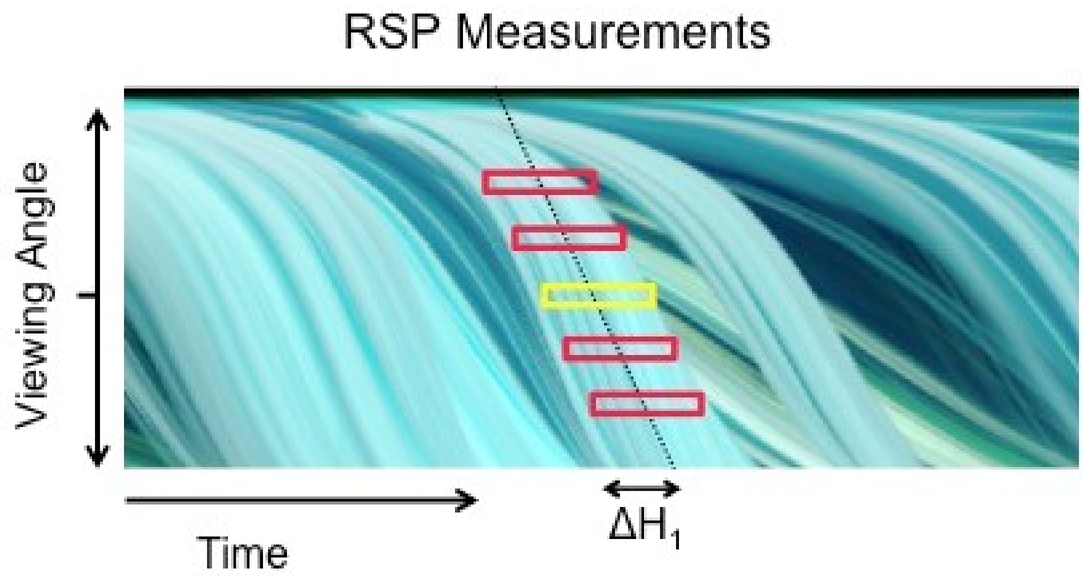
- Calculate the same correla for aggregated offsets ran from 0-20 km



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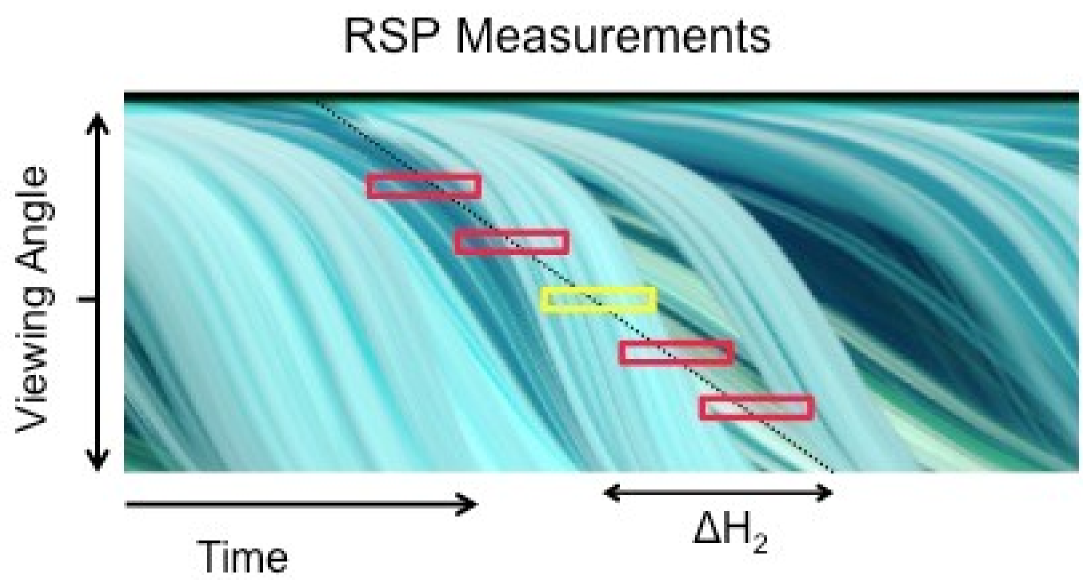

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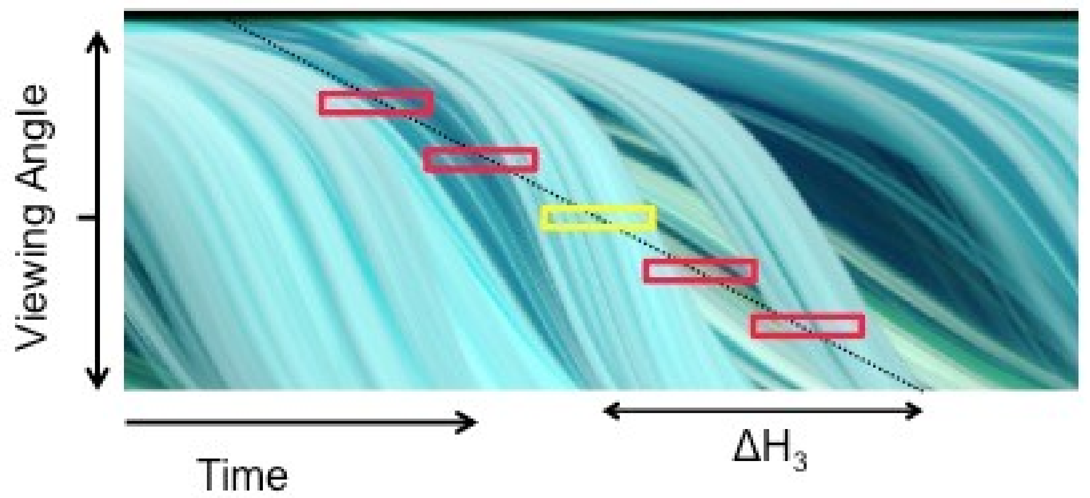
RSP Measurements



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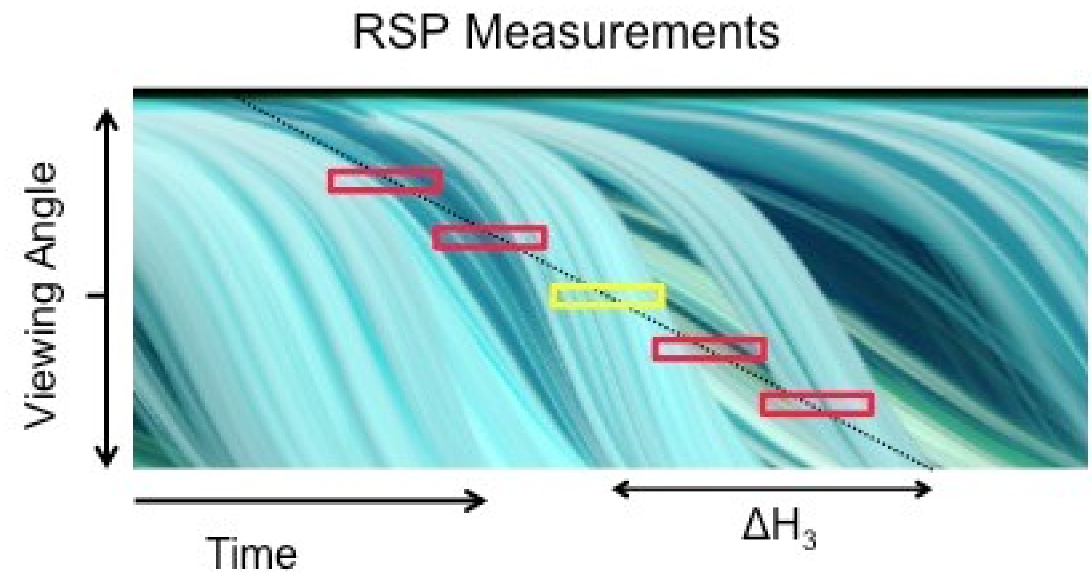
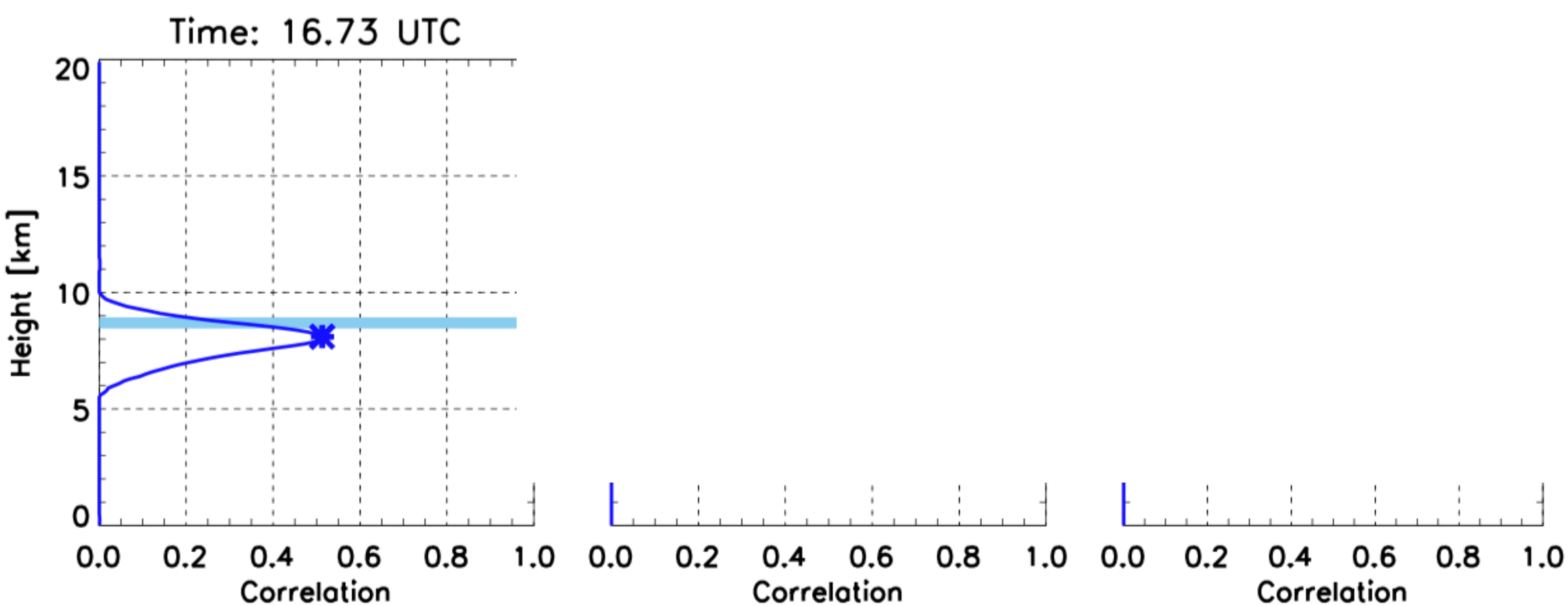
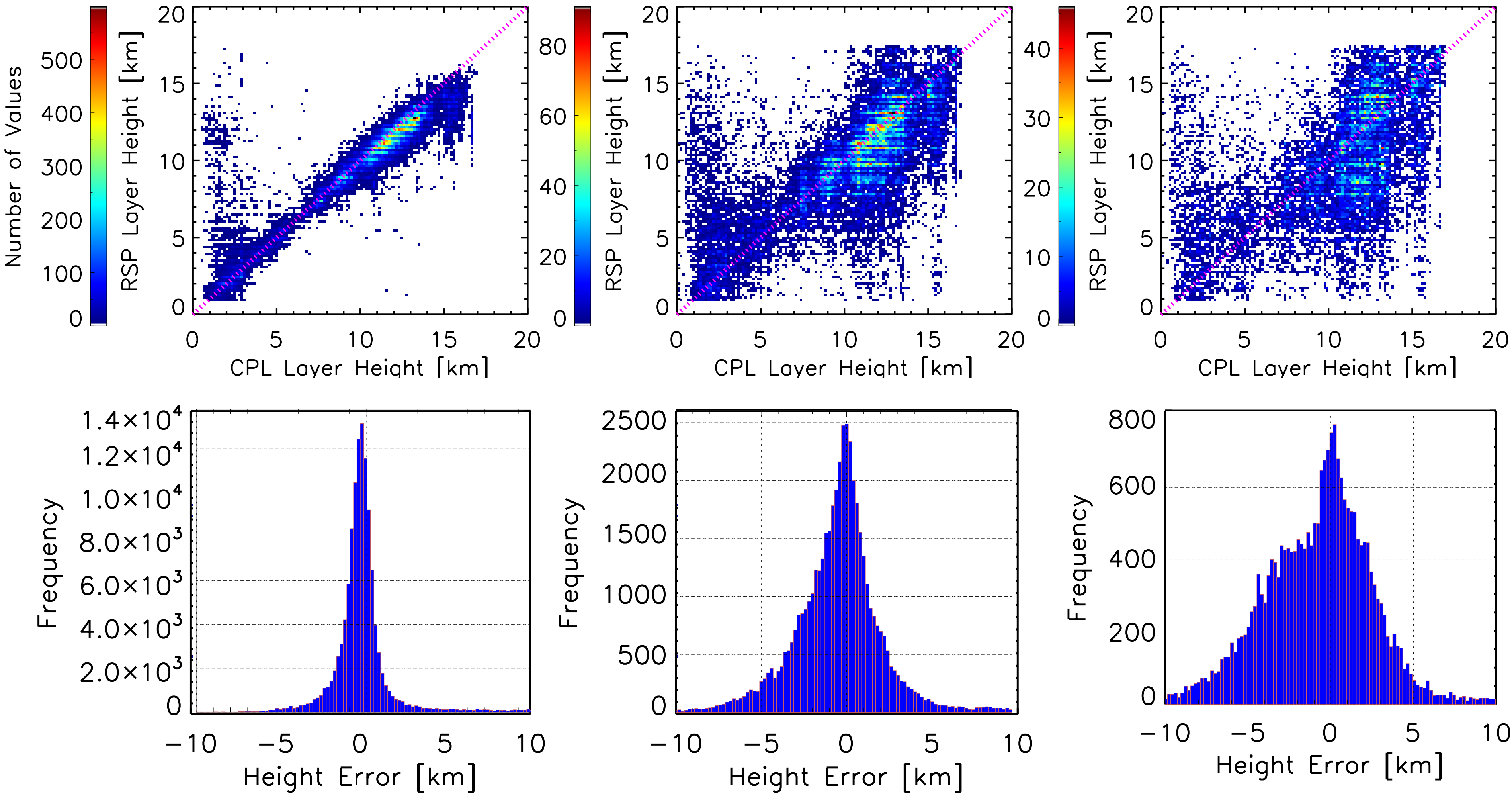




Results

1880 nm channel



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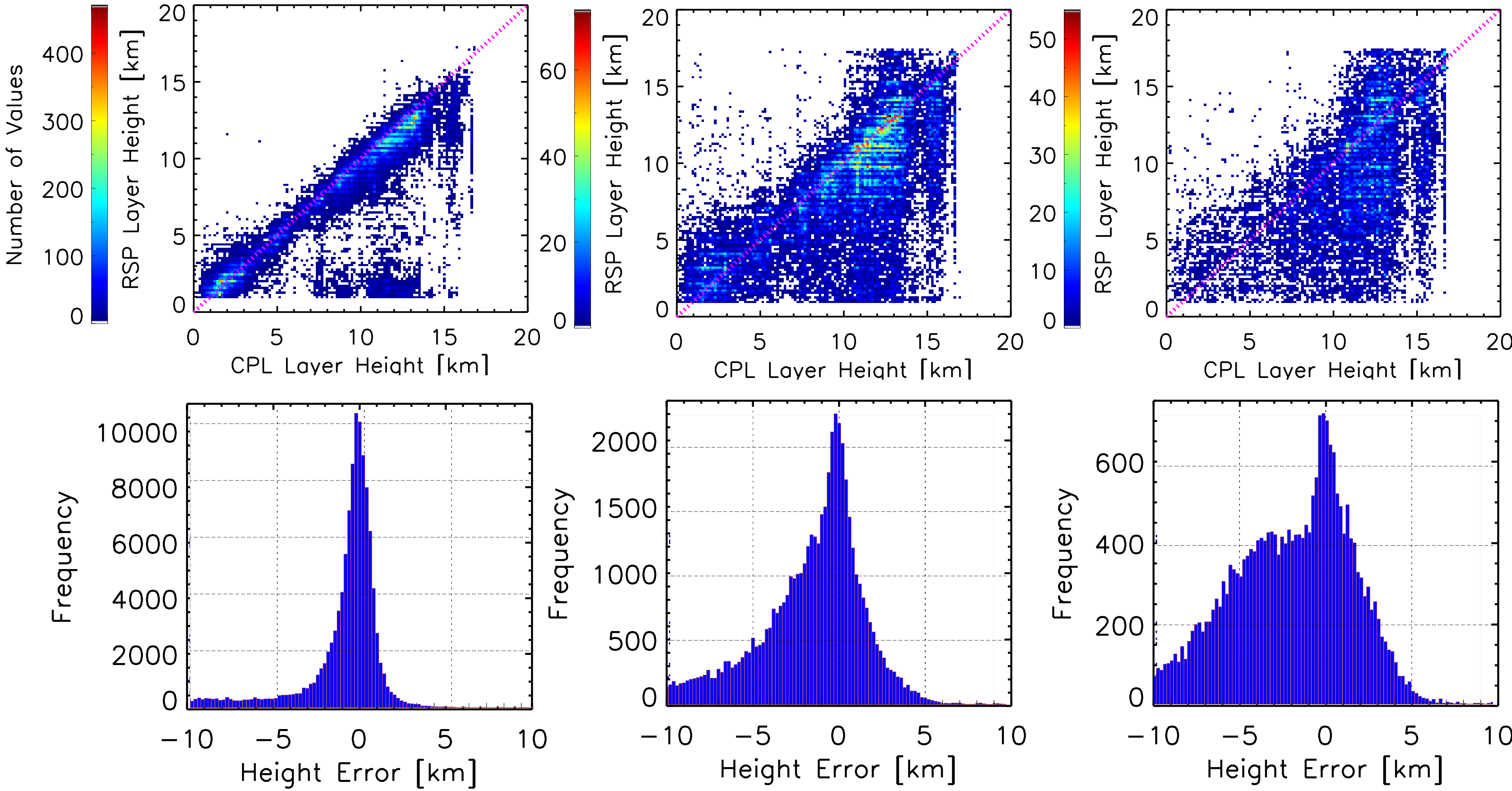
Results

670 nm channel



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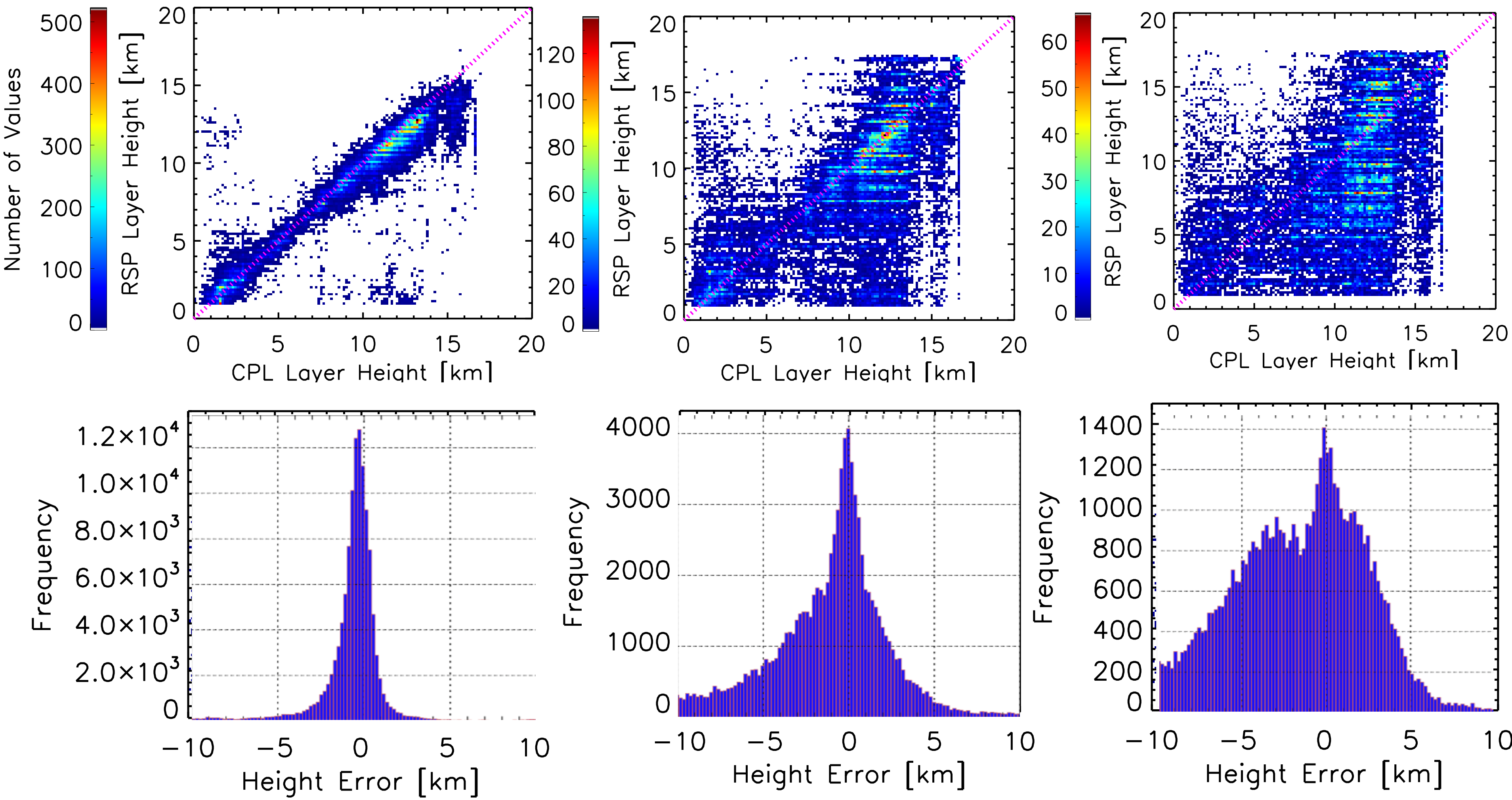
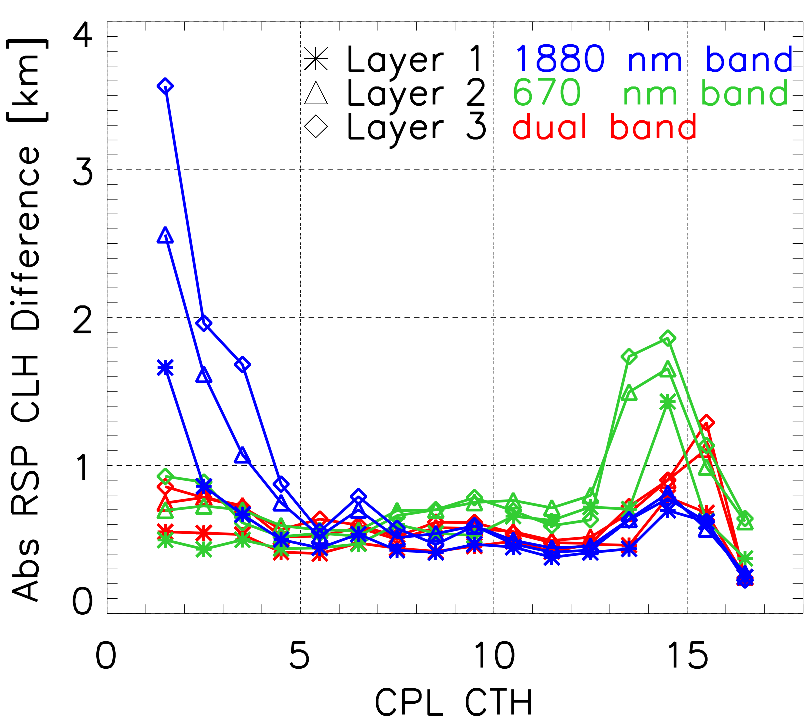
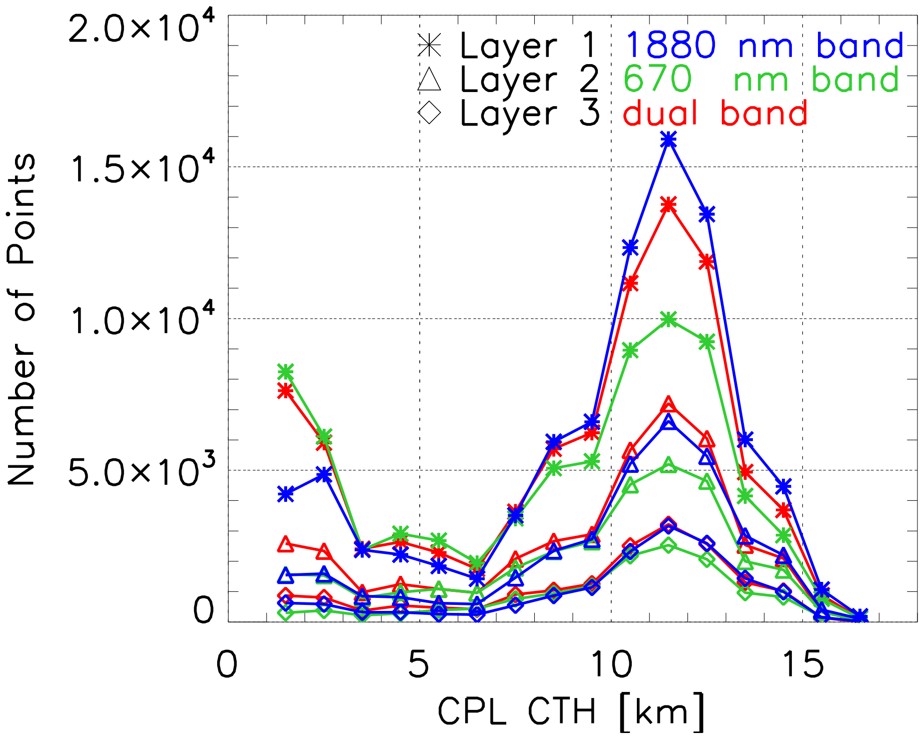
Dual channel



Results

Differences and Cloud Height





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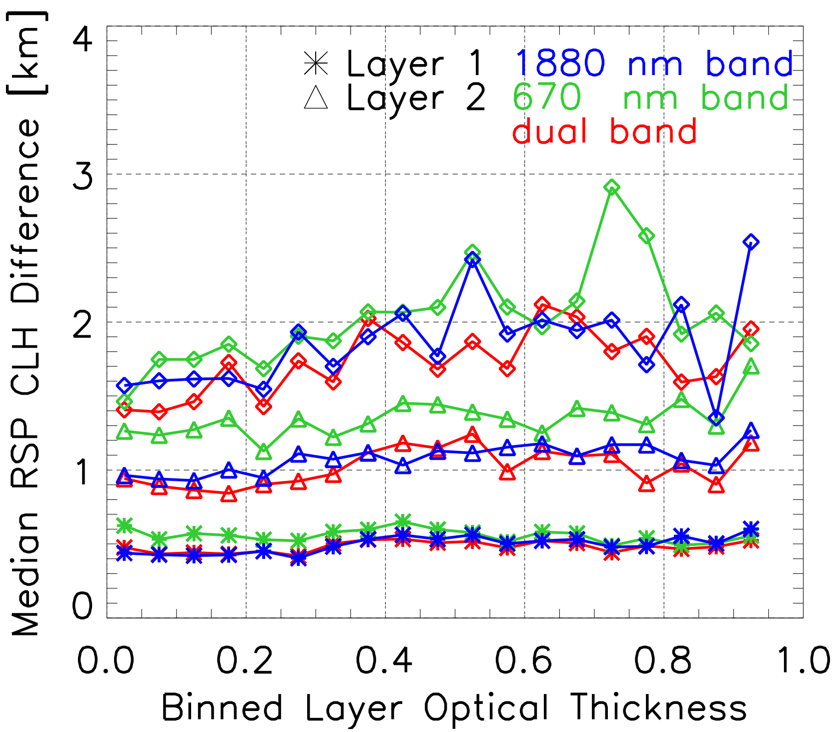
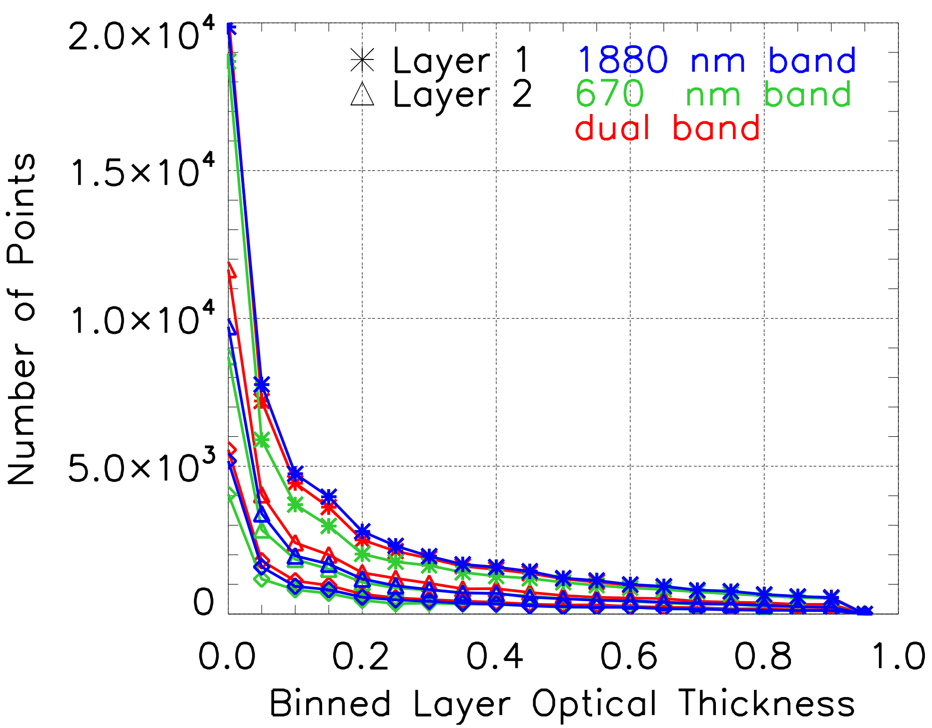
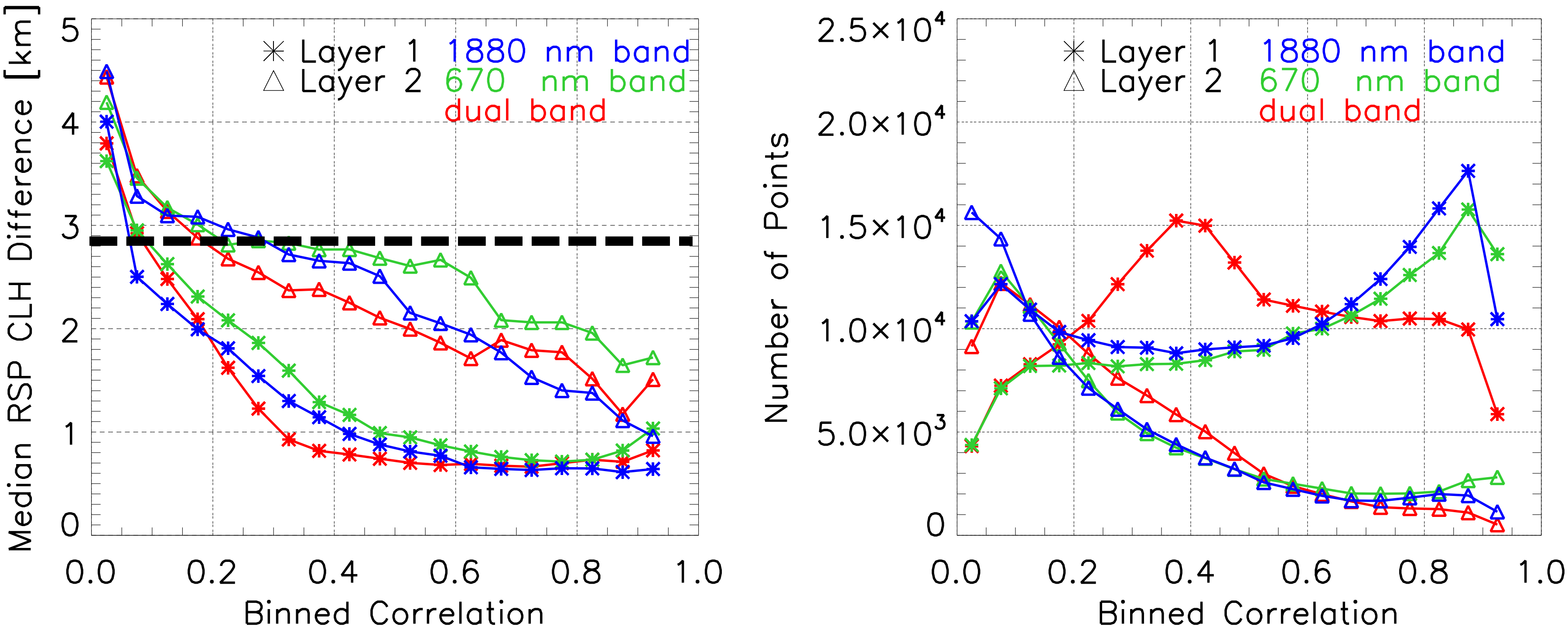
Differences and Cloud Optical Thickness





Results

Correlation for 1st and 2nd peaks

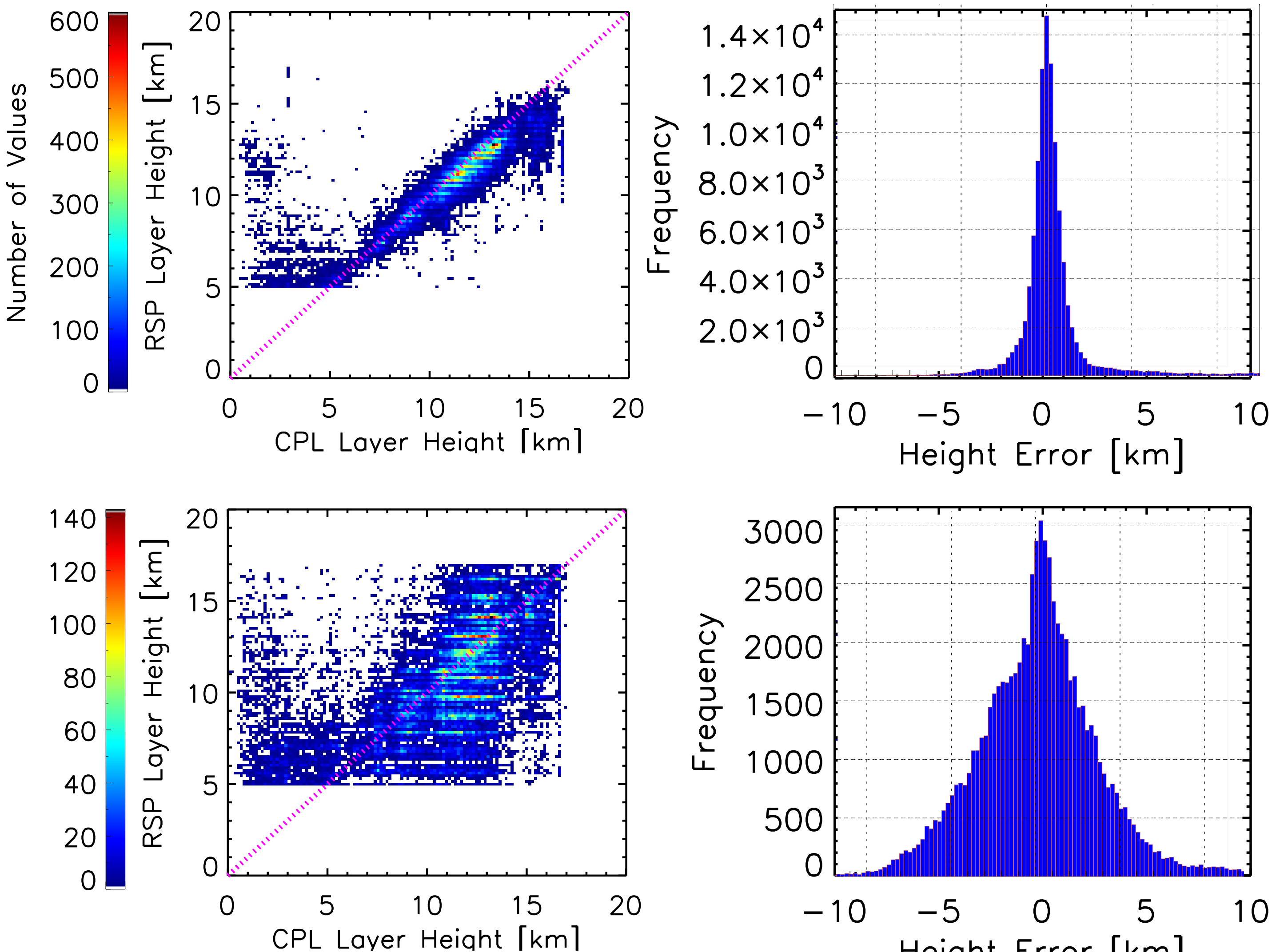


Results

1880 nm band

- Correlation cutoff: 0.0, 0.35, 0.60
- 5-17 km

- 1st peak median error: 0.43 km
- 2nd peak median error: 1.71 km
- 3rd peak median error: 2.49 km



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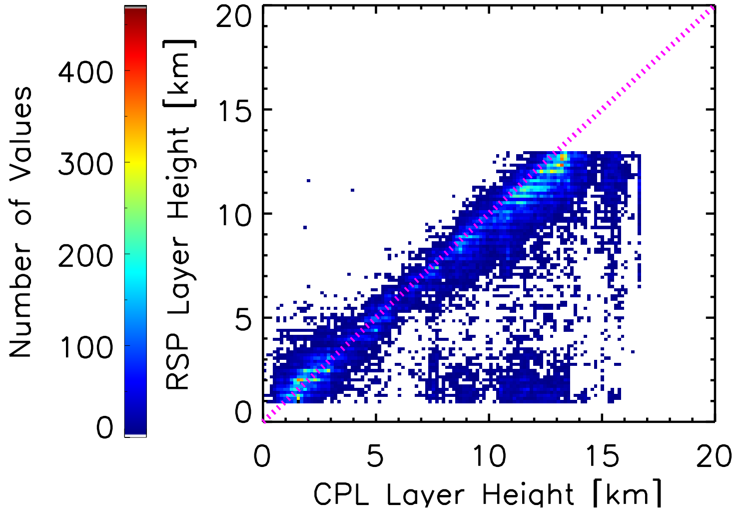
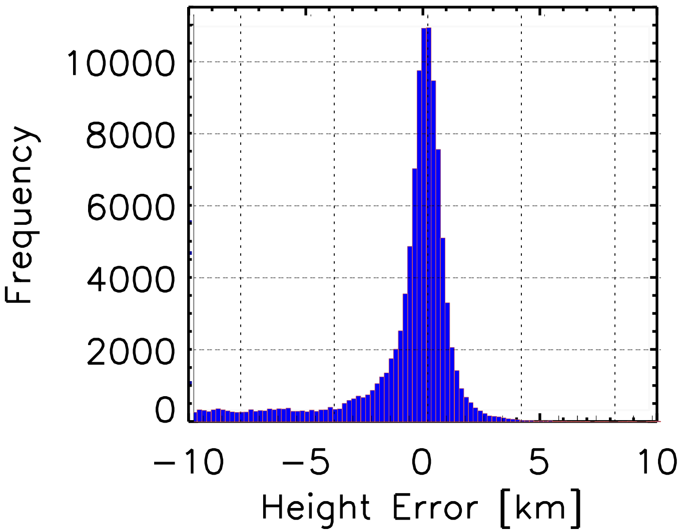
Results

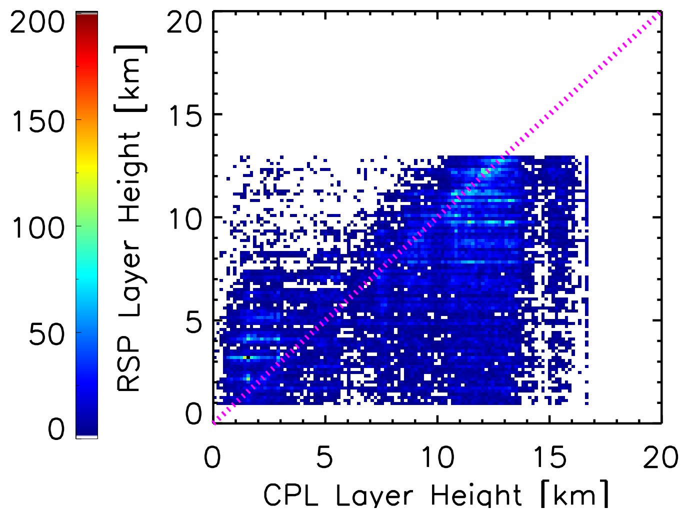
670 nm band

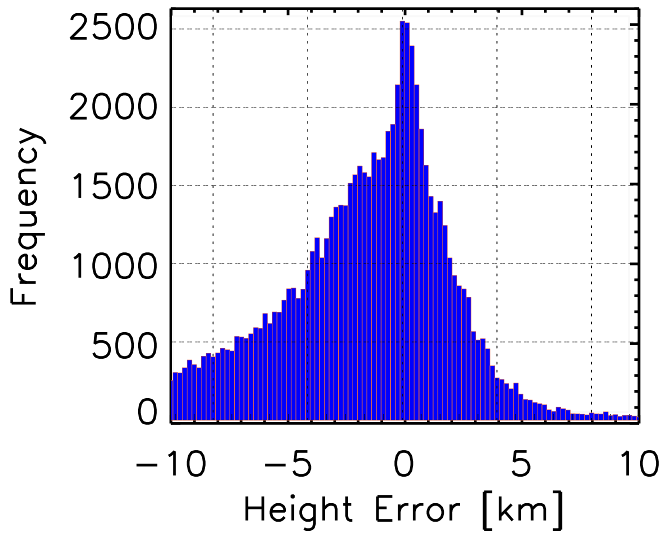
- Correlation cutoff: 0.0, 0.45, 0.60
- 1-13 km

- 1st peak median error: 0.57 km
- 2nd peak median error: 2.16 km
- 3rd peak median error: 3.02 km









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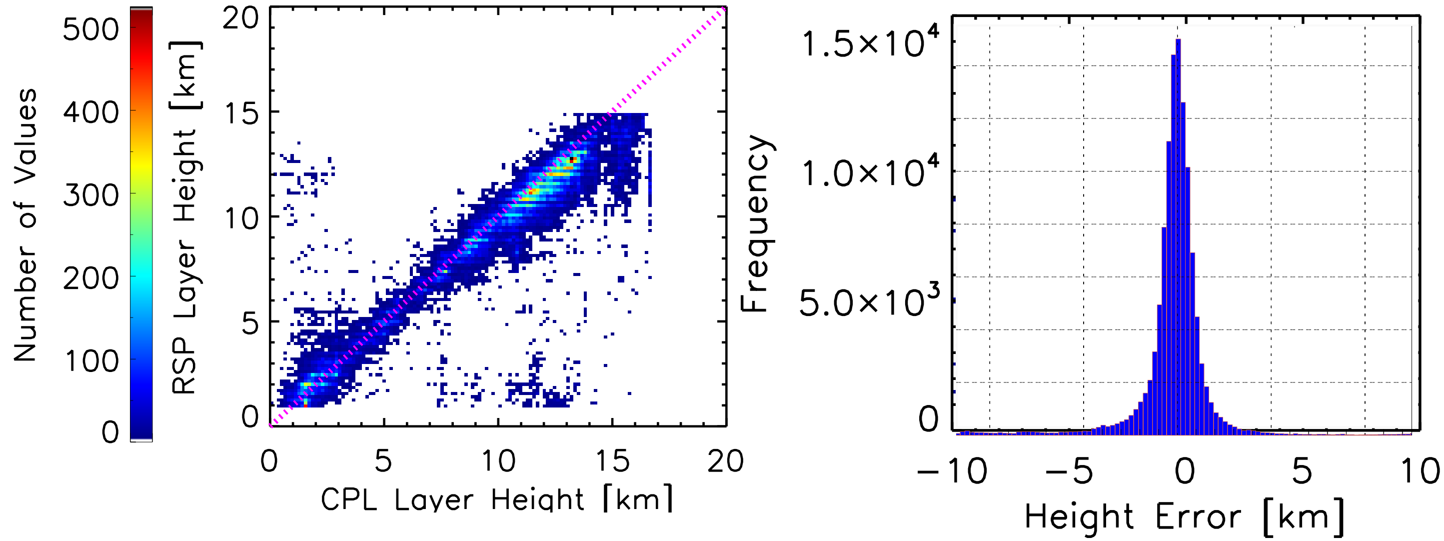
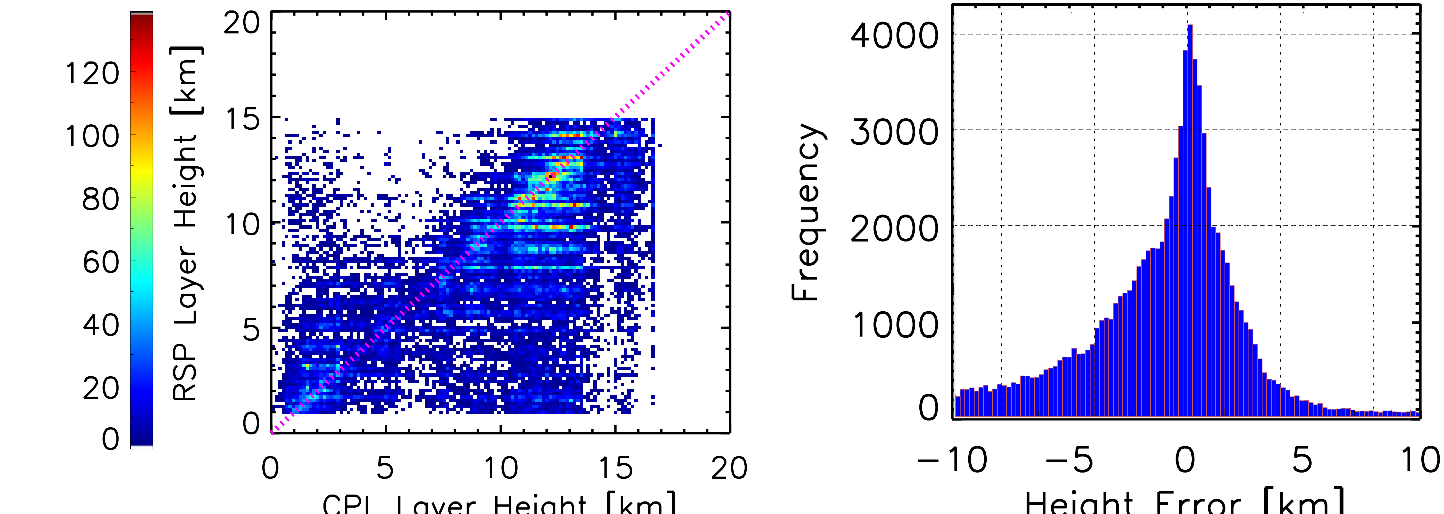
Results

Dual band

- Correlation cutoff: 0.0, 0.25, 0.60
- 1-15 km

- 1st peak median error: 0.45 km
- 2nd peak median error: 1.67 km
- 3rd peak median error: 2.66 km





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Summary

- Possible to use the RSP to retrieve multilayered cloud scenes
- Method works well for optically thin clouds (<0.05)
- The 1880 nm, 670 nm and dual bands consistently retrieve primary layer heights
- The dual band method is the most robust at determining multilayered scenes

Future Work

- Study the effect of using less angular measurements and degrading the spatial resolution
- Determine the magnitude of the effect of the object changing shape or position during the overpass (~3 minutes)

Extra

Thresholds

	1880 nm	670 nm	Dual
Cloud Top or Middle	Middle	Middle	Middle
Minimum COT	0.0	0.0	0.0
Minimum cloud height	5.0 km	1.0 km	1.0 km
Maximum cloud height	17.0 km	13.0 km	15.0 km
1st Peak Minimum Static Correlation	0.00	0.00	0.00
2nd Peak Minimum Static Correlation	0.35	0.45	0.25
3rd Peak Minimum Static Correlation	0.50	0.60	0.60

Performance

		1880 nm band	670 nm band	Dual Band
1st	**Median Error [km]**	0.43	0.57	0.45
	Np	105467	107476	116319
2nd	**Median Error [km]**	1.71	2.16	1.67
	Np	74170	75310	85530
3rd	**Median Error [km]**	2.49	3.02	2.66
	Np	40307	30805	47562

Cloud Top vs Cloud Middle

		1880 nm band		670 nm band		Dual Band	
		CPL Cloud Top	CPL Cloud Middle	CPL Cloud Top	CPL Cloud Middle	CPL Cloud Top	CPL Cloud Middle
1st	Median Error [km]	0.52	0.47	0.63	0.58	0.53	0.48
	Mean Error [km]	1.07	1.00	1.67	1.52	1.19	1.08
	Np	87447	87447	76262	76262	86223	86223
	Std. Dev.	2.03	1.91	2.91	2.83	2.28	2.18
	Corr. Coeff.	0.86	0.86	0.79	0.79	0.85	0.86
2nd	Median Error [km]	*1.26*	*1.27*	1.57	1.52	1.22	1.19
	Mean Error [km]	1.94	1.90	2.50	2.37	2.21	2.11
	Np	36176	36176	34755	34755	43145	43145
	Std. Dev.	2.88	2.77	3.44	3.34	3.35	3.26
	Corr. Coeff.	0.71	0.72	0.66	0.67	0.69	0.69
3rd	Median Error [km]	2.11	2.10	2.39	2.28	2.06	1.98
	Mean Error [km]	2.71	2.63	3.14	2.92	2.86	2.69
	Np	15939	15939	14049	14049	18012	18012
	Std. Dev.	3.65	3.52	3.71	3.59	3.70	3.57
	Corr. Coeff.	0.56	0.57	0.54	0.55	0.58	0.59

Extra

Number of Cloud Layers

Table 1: 1880 nm band RSP cloud scene fractions compared with CPL

RSP Scenes	Fraction	Corresponding CPL Layers					
		0	1	2	3	4	5
1 layer	0.32	0.1	0.46	0.27	0.12	0.04	0.01
2 layer	0.30	0.06	0.41	0.30	0.15	0.05	0.02
3 layer	0.37	0.05	0.40	0.31	0.16	0.07	0.02

Table 2: 670 nm band RSP cloud scene fractions compared with CPL

RSP Scenes	Fraction	Corresponding CPL Layers					
		0	1	2	3	4	5
1 layer	0.37	0.11	0.48	0.25	0.11	0.04	0.01
2 layer	0.36	0.10	0.44	0.27	0.13	0.04	0.01
3 layer	0.27	0.04	0.41	0.31	0.15	0.04	0.01

Table 3: Dual band RSP cloud scene fractions compared with CPL

RSP Scenes	Fraction	Corresponding CPL Layers					
		0	1	2	3	4	5
1 layer	0.31	0.12	0.53	0.23	0.08	0.03	0.01
2 layer	0.31	0.09	0.43	0.28	0.13	0.05	0.01
3 layer	0.38	0.05	0.40	0.31	0.16	0.07	0.02